Effects of trapping on rat populations and subsequent damage and yields of macadamia nuts

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During the 1990–1991 and 1991–1992 crop cycles, the effects of snap trapping on rat populations in a macadamia orchard and subsequent damage and yields of nuts were evaluated. During 1990–1991, 1681 roof rats (*Rattus rattus*), 22 Polynesian rats (*R. exulans*), and one Norway rat (*R. norvegicus*) were captured; 360 rats of undetermined species were captured during 1991–1992. Cumulative rat damage for the entire season varied from 0.36 to 1.34% of total annual production in the trapped sections, and from 1.71 to 3.62% of total annual production in the reference sections. However, trapping had no effect on yields: the number of nuts, mass per nut and the total mass of undamaged nuts did not differ between the trapped and reference sections. The results suggest the need to examine crop yield more closely in assessing methods for managing rodent infestations in macadamia orchards. The commonly used indices based on rodent activity and proportion of nuts damaged may overestimate the impact of rodent depredations and exaggerate the effectiveness of control measures in macadamia orchards. A large incidental take of birds points to the need for more selective techniques before trapping is utilized as a damage control measure in Hawaiian macadamia orchards.

Keywords: Macadamia nut; damage; yield; rodent control; *Rattus* spp.

Hawaii is the world's leading producer of macadamia nuts (*Macadamia integrifolia*). During the 1991–1992 crop cycle, Hawaiian growers produced ~27 000 t wet-in-shell macadamia nuts worth a net farm value of almost US$35 × 10^6 (Hawaii Agricultural Statistics Service, 1992).

In Hawaii, macadamia trees produce nuts throughout the year. An extended flowering period results in a prolonged harvest season that lasts from about June to February, with at least some mature nuts available throughout the year. Individual nuts take ~215 days to mature, after which they fall from the tree and are harvested mechanically or by hand (Cavaletto, 1983).

Roof rats (*Rattus rattus*) cause widespread damage in Hawaiian macadamia orchards. These arboreal rodents feed on macadamia nuts throughout the crop cycle, from the time that kernels are small, fleshy, unprotected fruits to when they are fully developed, high in oil content and surrounded by hard, brittle shells and fibrous outer husks. Most roof rat damage occurs in trees, with damaged nuts subsequently dropping to the ground. Norway rats (*Rattus norvegicus*) sometimes forage on fallen nuts, predominately in younger orchards with sparse canopy and abundant ground vegetation (Fellows, 1979, 1982).

Despite the apparent impact of rodents in macadamia orchards, few studies have documented damage. The only attempts of which the authors are aware measured nightly nut damage over short periods (Fellows, Sugihara and Pank, 1978; Pank *et al.*, 1978; Fellows, 1979). No studies have measured rat damage over an entire crop cycle, and none has assessed the effect of rat damage on yields. Fellows (1982) extrapolated from short-term studies and estimated that rats damage ~5% of the macadamia nut crop in Hawaii. However, such estimates may be misleading because both the quality and quantity of nuts, as well as rat damage, vary throughout the crop cycle. A better understanding is needed of the cumulative impact of rats over the entire crop cycle.

In the United States, zinc phosphide is the only toxicant registered for controlling rats in macadamia orchards. The federal registration labels allow application in orchards at any time during the crop cycle except within 30 days before harvest. In practice, this restriction makes it difficult to coordinate rodenticide applications with harvesting schedules. Most growers apply control measures after the harvest season, when mature nuts and competing labour demands are at a minimum. Few growers control rats during the 7–9 months of the year when nuts are harvested.

Trapping may provide an alternative means of reducing rodent populations and controlling damage in

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macadamia orchards. This approach allows control during the entire crop cycle. Although trapping has been considered too labour-intensive for most large-scale agricultural situations, it may be cost effective for high-value crops grown in limited areas.

During the 1990–1991 and 1991–1992 crop cycles, a study was conducted to (a) estimate the percentage of nuts damaged by rats over two crop cycles, (b) determine the effect of nut damage on yields, and (c) evaluate trapping as a means of reducing populations and controlling damage.

Materials and methods

Study area

The study was conducted at the Mauna Loa Macadamia Nut Corporation orchard in Keaau, ~17 km south of Hilo, Hawaii. The orchard comprised 999 ha and was divided into blocks separated by dirt roads and windbreaks of Norfolk Island pine trees (*Araucaria heterophylla*). Four blocks, ranging in size from 16.0 to 21.2 ha and containing 240 trees ha^{-1}, were selected for study. Most trees in the study blocks were 20 years old, but 17–23% were replants that replaced wind-damaged, diseased, or dead trees. One study block on the interior of the orchard was surrounded by other macadamia blocks; the other three were on the perimeter of the orchard. One perimeter study block abutted an overgrown abandoned orchard and the other two bordered a fallow area consisting of various native and introduced plants. No two study blocks were adjacent to each other.

Trapping

Half of each block was randomly selected for in-tree placement of 35–40 traps ha^{-1}; the other half of each block served as a reference. Previous trapping efforts and radiotelemetry studies indicated minimal rat activity on the orchard floor (M. E. Tobin, R. T. Sugihara and A. E. Koehler, unpublished data); no rats were trapped on the ground, therefore.

In the sections selected for trapping, one rat snap trap (McGill Metal Products Company, Marengo, IL, USA or Woodstream Corporation, Lititz, PA, USA) was secured to approximately every fourth tree in each of two adjacent rows in an alternating pattern. Every third row was excluded from trapping. Only trees that appeared healthy, bore nuts, and had an accessible, horizontal to moderately sloping lateral branch for trap placement were used. If a tree was missing or otherwise inappropriate for trap placement, an adjacent tree was selected within the same row.

The nuts were harvested four or five times per crop cycle in each block, at approximately 6-week intervals depending on weather, nut drop, and labour availability. Rats in each block were trapped as soon as possible after each harvest, and twice during the non-harvest season.

During each trapping session, the traps were prebaited with chunks of coconut and secured, unset, to lower lateral branches with rubber bands; 3 or 4 days later, the traps were baited with fresh coconut, set, and monitored daily for 2 weeks. During the first crop cycle, from June 1990 to April 1991, traps were set on Monday of the first week, inactivated at the weekend, and rebaited with fresh coconut on Monday of the second week. There were eight nights of active trapping during each 2-week trapping session. Rodent carcasses were removed, the species of each capture recorded, and traps rebaited as necessary.

During the second crop cycle, from June 1991 to February 1992, the traps were checked only once weekly, were not inactivated at the weekend, and were rebaited only at the beginning of the second week. Rat species were not identified during the second crop cycle because many carcasses were decomposed beyond identification or were partially or wholly removed by scavengers.

Analysis of variance (ANOVA) was used to compare trap success between the trapped and reference sections and among trapping sessions for each of the two crop cycles (SAS Institute Inc., 1988). Total number of rats captured of all species was a dependent variable, orchard block was a random effect, and trapping session was a fixed effect. Pairwise comparisons were made with Duncan's multiple range test; differences were judged significant at the 0.05 level.

Damage and yield assessment

Damage and yields were estimated 1–2 days before each scheduled harvest by dividing each trapped and reference section into five strata, each with an equal number of trees, and randomly selecting either four (1990–1991) or six (1991–1992) healthy, nut-bearing trees per stratum. Twenty trees were selected per section during 1990–1991 and 30 trees per section during 1991–1992.

Each randomly selected tree and three adjacent trees were used to define the four corners of a sampling plot with easily recognizable boundaries. Each sampling plot contained a quadrant from each of four trees and encompassed an area equivalent to that under a single tree.

During each assessment, both the number of nuts (regardless of size) damaged by rats and the number of undamaged full-size nuts on the ground inside each sampling plot were counted, and the percentage damaged by rats was calculated. The total mass of all full-size (> 1.5 cm diameter) undamaged nuts that had husks and shells was recorded, but not the number or mass of undamaged, immature nuts. Wet-in-shell yields were derived by dividing wet-in-husk masses in half. The varieties and trunk diameters of the four trees in each sampling plot also were recorded.

Separate ANOVA procedures were used to analyse damage and yields for each of the two crop cycles (SAS Institute Inc., 1988). Treatment and harvest session were fixed effects, and orchard block was a random effect. The effect of tree size on yield was adjusted for by dividing the mass and number of nuts in each sampling plot by the average cross-sectional area of the trunks of the four trees 30 cm above the ground. The first harvest of the 1990–1991 crop cycle was excluded from the data analyses because it was conducted before trapping started.

Records were kept of (a) the number of people and time required to set and check the traps and to prepare the coconut bait, (b) traps, bait and other material costs, and (c) the costs of an all-terrain vehicle (ATV). Labour and costs associated with measuring damage and yields were not used in the cost–benefit analyses.

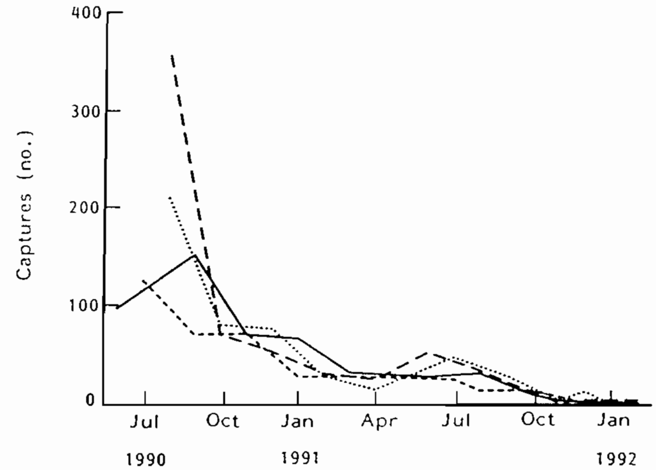

Figure 1. Number of roof rats (*Rattus rattus*) captured in each of four Hawaiian macadamia orchard blocks (——, field 2; – – – –, field 5; . . . ., field 7; — — —, field 19) during the 1990–1991 and 1991–1992 crop cycles

Results

Rat captures

1990–1991 crop cycle. A total of 1681 roof rats, 22 Polynesian rats (*R. exulans*), and one Norway rat were trapped during five 2-week trapping sessions in the four blocks (*Figure 1*). Capture success differed among trapping session ($F = 5.14$; 4, 12 d.f.; $p = 0.012$) but not among blocks ($F = 0.47$; 3, 12 d.f.; $p = 0.71$). More rats were captured during the first trapping session than during any subsequent trapping session.

Relatively few traps captured more than one rat per trapping session. During the first week of any trapping session, an average of 42.6 traps per block captured one rat, 6.8 traps per block captured two rats, and 2.1 traps per block captured more than two rats. During the second week, an average of 19.9 traps per block captured one rat, 0.9 traps per block captured two rats, and 0.1 traps per block captured three rats. Little benefit was derived, therefore, from checking the traps daily and resetting those that had captures.

Captures other than rats included one house mouse (*Mus domesticus*), two Indian mongooses (*Herpestes auropunctatus*), 435 northern cardinals (*Cardinalis cardinalis*), 11 Japanese white-eyes (*Zosterops japonicus*), one melodious laughing-thrush (*Garrulax canorus*), and three unidentified birds.

1991–1992 crop cycle. A total of 360 rats were captured in the four blocks during six 2-week trapping sessions (*Figure 1*). Based on a sample of 200 rats retained from this group for a food habits study, roof rats and Polynesian rats comprised 92 and 8%, respectively, of the orchard population.

Indian mongooses, feral cats (*Felis silvestris*), and barn owls (*Tyto alba*) were common in and around the orchard and undoubtedly removed some of the captures. Occasionally, only a head, fur, or other remnants of rats were found in traps.

Rat captures during the second crop cycle differed among trapping sessions ($F = 16.47$; 5, 15 d.f.; $p = 0.0001$) but not among blocks ($F = 1.86$; 3, 15 d.f.; $p = 0.18$). More rats were captured during the first trapping session than during any subsequent trapping session, and more during the second trapping session than during any subsequent session (*Figure 1*). With one exception, capture success declined to < 15 rats per block during the third and subsequent trapping sessions.

Captures other than rats included one domestic mouse, one Indian mongoose and 241 birds.

Damage

1990–1991 crop cycle. Rats damaged an average of 1.61% of the nuts sampled in the trapped sections and 4.76% of the nuts sampled in the reference sections ($F = 52.08$; 1, 3 d.f.; $p = 0.005$) (*Figure 2*). Percentage damage did not differ significantly among harvest periods ($F = 1.92$; 3, 8 d.f.; $p = 0.20$). Cumulative rat damage for the entire season varied from 0.73 to 1.34% of total production in the trapped sections, and from 1.99 to 3.62% of total production in the reference sections ($F = 14.70$; 1, 3 d.f.; $p = 0.03$). These estimates are conservative because some damaged nuts that were < 110 days old and without shells probably decomposed between the time when the nuts fell and when damage was assessed. Nuts cached by rats in underground burrows also escaped detection.

1991–1992 crop cycle. Rats damaged an average of 0.94% of the nuts sampled in the trapped sections and 3.32% of the nuts sampled in the reference sections ($F = 98.44$; 1, 3 d.f.; $p = 0.002$) (*Figure 2*). Percentage damage differed among harvest periods ($F = 29.99$; 4, 9 d.f.; $p = 0.0001$), mainly as a function of total nut production. Relatively more nuts were damaged during the first harvest period, when production was lowest, than during any other period, and during the fourth and fifth harvest periods, when seasonal production was tapering off, than during either the second or third harvest period when production was at a peak. Cumulative rat damage for the entire season varied from 0.36 to 1.10% of total production in the trapped sections,

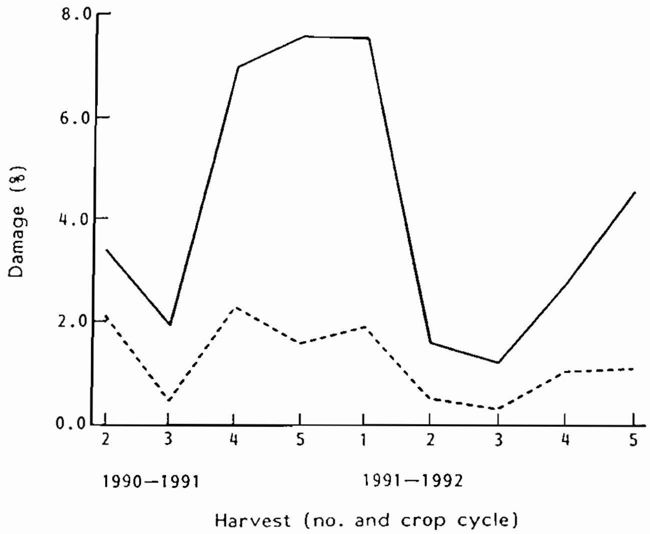

Figure 2. Mean percentage of macadamia nuts damaged by roof rats (*Rattus rattus*) per harvest in sections containing (– – – –) or not containing (——) traps in four Hawaiian orchard blocks during the 1990–1991 and 1991–1992 crop cycles. The first harvest of the 1990–1991 crop cycle was excluded because it preceded the initiation of the study

and from 1.71 to 3.05% of total production in the reference sections ($F = 31.06$; 1, 3 d.f.; $p = 0.01$).

Yields

1990–1991 crop cycle. When standardized for tree size, the wet-in-husk mass of full-size, undamaged nuts varied little between the trapped and reference sections ($F = 0.97$; 1, 3 d.f.; $p = 0.40$). Estimated average total annual wet-in-shell yield was 6515 kg ha^{-1} in the trapped sections and 6868 kg ha^{-1} in the reference sections (*Figure 3*). Yields varied among harvest periods ($F = 10.43$; 3, 8 d.f.; $p = 0.004$), with more nuts harvested during the third period than any other period, and during the second period than during the fourth or fifth period. The number of undamaged full-size nuts ($F = 0.85$; 1, 3 d.f.; $p = 0.42$), mass of individual undamaged nuts ($F = 0.40$; 1, 3 d.f.; $p = 0.57$), and total number of nuts (damaged and undamaged) ($F = 0.42$; 1, 3 d.f.: $p = 0.56$) did not vary between the trapped and reference sections.

1991–1992 crop cycle. Standardized wet-in-husk mass of full-size, undamaged nuts varied little between the trapped and reference sections ($F = 0.08$; 1, 3 d.f.; $p = 0.80$). Estimated total wet-in-shell yield averaged 7310 kg ha^{-1} in the trapped sections and 7585 kg ha^{-1} in the reference sections (*Figure 3*). Yields varied among harvest periods ($F = 18.01$; 4, 9 d.f.; $p = 0.0003$) (*Figure 3*), with more nuts harvested during the second and third periods than at any other time, and during the first period than during the fourth or fifth period. Fewer nuts were harvested during the fifth period than during any other time. The number of undamaged full-size nuts ($F = 0.02$; 1, 3 d.f.; $p = 0.89$), the mass of individual undamaged full-size nuts ($F = 1.51$; 1, 3 d.f.; $p = 0.31$), and the total number of damaged and undamaged nuts ($F = 0.00$; 1, 3 d.f.; $p = 0.99$) differed little between the trapped and reference sections.

Costs of the trapping programme

1990–1991 crop cycle. Prorated over 3 years, traps cost US\$8.83 ha^{-1} year^{-1}. The rubber bands cost US\$6.65 ha^{-1} year^{-1}. Labour and materials for applying waterproofing sealant to the traps averaged US\$2.10 ha^{-1} year^{-1}. Coconut and labour for preparing bait averaged US\$26.24 ha^{-1}. The labour for setting and checking the traps amounted to US\$278.59 ha^{-1}. The ATV averaged US\$18.29 ha^{-1} year^{-1}. The total cost associated with the trapping programme was US\$340.70 ha^{-1}.

1991–1992 crop cycle. During 1991–1992, when traps were checked weekly instead of daily, costs associated with purchasing and preparing bait averaged US\$14.99 ha^{-1}, or 43% less than in 1990–1991. Labour for setting and checking the traps averaged US\$181.08 ha^{-1}, or 60% less than in 1990–1991. Costs for the ATV were reduced by 35%, to an average of US\$11.86 ha^{-1}. The estimated average costs for traps, rubber bands and waterproofing were the same as for the 1990–1991 crop cycle. The average cost of conducting the modified trapping programme was US\$225.51 ha^{-1}.

Discussion

This study is the first to measure rat damage through an entire macadamia crop cycle. Cumulative rat damage ranged from 1.99 to 3.62% of total production during 1990–1991, and from 1.71 to 3.05% of total production during 1991–1992, in the sections where no rat controls were employed.

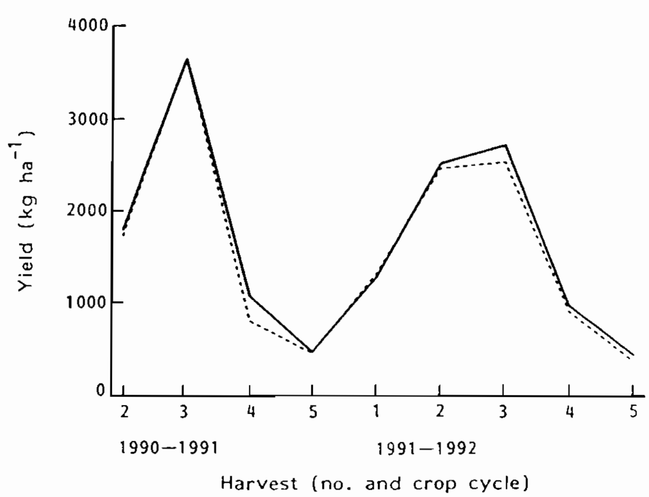

Figure 3. Mean wet-in-shell yields of undamaged, full-size macadamia nuts in sections containing (– – – –) or not containing (——) traps in four Hawaiian orchard blocks during the 1990–1991 and 1991–1992 crop cycles. The first harvest of the 1990–1991 crop cycle was excluded because it preceded the initiation of the study

The steady decline in capture success over the course of the study indicates that trapping effectively reduced the local rat population in the macadamia blocks studied. The reduced nut damage in the trapped sections indicates that lowering pest populations reduced damage to developing macadamia nuts.

The average cost of the trapping programme for the 1990–1991 crop cycle was US\$340.70 ha^{-1}. Based on US\$1.66 kg^{-1}, the average 1990–1991 farm price for wet-in-shell macadamia nuts in Hawaii (Hawaii Agricultural Statistics Service, 1991), and on an average yield of 7000 kg ha^{-1} of wet-in-shell nuts without employing rat-control measures (estimated in this study), yields would need to increase by 3.0% to pay for the costs of the trapping programme. To recoup the US\$213.65 expended per hectare in 1991–1992 for the modified trapping programme, a yield of 7000 kg ha^{-1} would require an increase of 1.8% to pay for the trapping programme.

However, the lower damage in the trapped sections was not reflected in higher yields. Trapping had little effect on the number of undamaged full-size nuts, mass per undamaged full-size nut, or total mass of undamaged full-size nuts. After controlling for variation due to orchard location, tree variety and tree size, no difference was detected between the trapped and reference sections with respect to any of these yield variables.

Nut production varies greatly among years, fields, trees, and even branches on the same tree (G. Ueunten and A. Yamaguchi, unpublished data), and is influenced by many factors (e.g. pollination, fruit set, weather, drainage, insect damage and disease) besides rats. A larger sample size probably is needed to detect any reduction in yield attributable to the low levels of rat damage observed in this study.

Rat damage accounted for only a small percentage of the premature nut drop. Macadamia flowers and fruits abscise continuously from anthesis through fruit maturity (Sakai and Nagao, 1984). More than 90% of the 200–300 flowers on a typical raceme drop within 2 weeks after anthesis, and > 80% of the fruit set abscises within the first 6 weeks. After this, premature nut drop continues at a lower rate until maturity at 28–30 weeks. Less than 1% of the flowers on a raceme develop to maturity (Sakai and Nagao, 1984).

This high natural abortion rate of macadamia nuts may have overshadowed any effect that rat damage may have had on yields. A similar phenomenon has been observed with insect damage. Jones and Tome (1993) reported that the correlation between *Cryptophlebia* spp. feeding on developing macadamia nuts and premature nut drop is weak when damage levels are less than ~25%.

Macadamia trees may have compensated for rat damage by retaining nuts that might otherwise have dropped prematurely. Nagao, Kobayashi and Sakai (1988) suggested that the bearing capacity of macadamia trees is limited, and that unknown factors limit final nut set. Interactions among nuts on a single raceme may control abscission (Sakai and Nagao, 1980), and low levels of damage may simply determine which nuts drop.

Most studies of premature macadamia nut drop have concentrated on the early part of the maturation process (Sakai and Nagao, 1980; Ueunten, 1989); little attention has focused on the second half of the developmental process. However, nuts do not reach full size and begin to accumulate appreciable amounts of fatty acids until ~111 days after flowering (Cavaletto, 1983), and it is during this period that rats may cause the most damage. A better understanding of the dynamics of premature nut drop during the latter half of the crop cycle may be needed to determine the effects of rat damage on yields.

A major concern in the trapping programme was the large number of birds captured, mostly northern cardinals. All of the identified non-target species captured were introduced into Hawaii, and some have played a significant role in the decline of native Hawaiian birds (Banko and Banko, 1976; Mountainspring and Scott, 1985) and in the spread of exotic weeds (Stone, 1985). Nevertheless, pest-control programmes should be specific for the species of concern. Covering the traps, using a different bait, or colouring the bait (Kalmbach and Welch, 1946; Brunner and Coman, 1983) might provide a means of reducing captures of birds.

Management implications

Although extensive and persistent snap trapping can reduce rat populations and lower depredations in macadamia orchards, it apparently has little effect on yields of mature nuts, at least at the levels of damage (< 5%) observed in this study. This calls into question the most commonly used criteria for evaluating the impact and control of rats in macadamia orchards. Estimating populations and assessing damage may overestimate the impact of rodent depredations and exaggerate the effectiveness of control measures. More study is needed to clarify the relationship of these variables throughout the macadamia nut crop cycle to the yield of mature nuts. The large incidental take of birds points to the need for more selective techniques before trapping is utilized as a damage-control measure in Hawaiian macadamia orchards.

Notes and acknowledgements

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